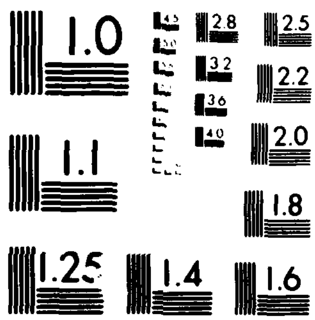
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SUMMARY OF THE ADVANCED TELEOPERATOR TECHNOLOGY CONFERENCE

Edited by DC Smith
Code 5331

April 1980

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA 92152

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

SL GUILLE, CAPT, USN
Commander

HL BLOOD
Technical Director

ADMINISTRATIVE INFORMATION

The conference/workshop reported here was conducted as a part of the Advanced Teleoperator Technology program: a 6.2-funded effort sponsored by the Naval Material Command.

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Released by
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Under authority of
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Environmental Sciences Department

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An advanced Teleoperator Technology Conference/Workshop was conducted to initiate investigations needed to identify parameters and goals for advanced teleoperator development. The conference program examined background, history and objectives, and included presentations by sensory experts, as well as open forum discussions relating to subsystems that would acquire, transmit and display direct and extended sensory information to a remote operator. The development of such subsystems would enable an operator to project himself into remote and possibly hostile environments.

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INTRODUCTION

The Advanced Teleoperator Technology program is a NAVMAT-funded 6.2 effort with two major objectives. The first objective is to integrate and advance the technologies relevant to the development of advanced general teleoperator systems, and secondly, to demonstrate the technical feasibility and advantages of these advanced systems to perform a variety of important Navy and Marine Corps warfare and support missions.

This program is based on the concept that a remote system which capitalizes on the extensive capabilities and adaptability of man needs to be investigated. Man is incorporated into the system's control loops because his unique ability to reason and adapt to changing conditions cannot be replaced with near-term available computer systems (i.e., robots).

A part of this program will develop the technology necessary to supply an operator with remotely-obtained direct and extended sensory information which will enable the operator to project himself into remote, and possibly hostile, environments. Situations where such a system might provide the operator with a safe, on-the-scene presence are diving operations; emergency rescue and repair; handling of nuclear, biological, and chemical materials; combat operations in support of amphibious or tactical warfare ashore; and space operations.

It is our intention to begin investigation of those subsystems that will acquire, transmit, and "display" direct and extended sensory information to the operator in order that he "feel" presence at the remote site.

To initiate these investigations, the Advanced Teleoperator Technology Conference/ Workshop was conducted October 3–4, 1979, at the Naval Post-Graduate School, Monterey, California. The conference, hosted by the Naval Ocean Systems Center (Hawaii Laboratory), was attended by leading researchers from universities, research institutes, program sponsors, and other Navy representatives with expertise in technology-related areas. A complete list of participants and their areas of expertise follows this introduction. Several of the participants are involved in development of aids for the handicapped; others are experts on different sensory modalities (i.e., vision, audition, olfaction).

The two-day conference began with a statement of the program background, history, and objectives, followed by a series of presentations by the invited sensory experts which included brief discussions of the present state of the art within their fields, and their past and present work. The conference concluded with an afternoon devoted to open forum discussions.

The following conference proceedings are presented in three parts. First, the opening remarks by the sponsor and program management are summarized. Second, brief overviews of each of the presentation made by the individual participants are reported. Formal papers and visual aids have not been included in these proceedings, so it is left to the reader to contact the individual participants for further information. Finally, the open forum discussions are summarized according to the topics discussed.

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Electrocutaneous perception.
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Dr. Gerald S. Malecki, Office of Naval Research

Dr. Yee-Yeen Chu, Perceptronics, Representative for Office of Cybernetics Technology, Defense Advanced Research Projects Agency

SPONSORS

Glenn R. Spalding, Naval Material Command

Lt. Col. Ray W. Bowles, U.S.M.C.

DOCUMENTATION

Ronald H. Schneider
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Document conference.

OPENING REMARKS

David C. Smith (NOSC, Hawaii) – Introduction of Participants and Conference Purpose

The participants in the conference were introduced and their organizational affiliations and areas of expertise were mentioned (see preceding list). It was explained that to initiate the first year's program effort, the conference was called to have sensory experts interact with Navy scientists and engineers. Participants were instructed to discuss and conceptualize approaches for acquiring and "displaying" sensory information to system operators so that they feel presence at a remote site.

Information sent to the attendees prior to the conference was discussed, and each invited sensory expert was asked to include in his presentation a technology forecast from within his area of expertise for the next 5- to 15-year period. "How to create realism" was explained to be the overall theme.

Glenn R. Spalding – Sponsor Opening Remarks

Mr. Spalding, from NAVMAT, and the prime sponsor of the program, stated that the program was in the early stages of exploratory development. He explained that the conference and program should attempt to assess the technologies relevant to advanced teleoperators and their application to Navy and Marine Corps needs. He said the program should meld the technologies with the applications.

James K. Katayama (NOSC, Hawaii) – Program Goals and Approach

The need for teleoperators, and the objectives and approach to the program, were presented.

Mr. Katayama explained that some of the technologies necessary to develop new, advanced teleoperators already are available or are moving ahead quite rapidly. The areas that are progressing well are those pertaining to high quality data links, specifically coaxial cables and fiber optics. Artificial intelligence is developing, but it is unable to handle undefined, unpredictable situations; thus, autonomous teleoperators (i.e., robots) are not practical.

In order to build the new generation of teleoperators that NOSC envisions, it will be necessary to make man an integral part of the control loop. With man in the loop, an interactive system can be built that will enable the adaptability of man to be exploited. Mr. Katayama explained that it had been decided to emphasize obtaining and displaying high-quality, remote sensory data for the remote system operator.

The senses of vision, hearing, olfaction, taste and touch were mentioned as topics to be discussed during this conference. He also expressed his interest in investigating a new generation of remote manipulators with sensory feedback.

The Advanced Teleoperator Technology program intends to develop the necessary subsystem building blocks that could be immediately incorporated into a mission-specific system and which might eventually be integrated into a more generic teleoperator system. Specific applications will be examined, and the subsystem building blocks will be tailored to those applications utilizing money from sources other than the 6.2 program. It was emphasized that the program should not focus strictly on underwater applications.

FORMAL PRESENTATIONS

Dr. Ross L. Pepper – Vision

Dr. Pepper reviewed the literature, theories and models of vision and summarized ongoing visual perception research as it relates to future teleoperator systems. The review covered topics ranging from the neurophysiology of the eye to the ONR-funded work on display devices.

Work done on stereoscopic displays at NOSC's Hawaii Laboratory was described. Dr. Pepper's efforts have been directed toward exploring the differences in remotely-viewed manipulator task performance while using stereoscopic or monocular display systems. His research has shown that stereo provides a performance advantage under different levels of reduced visibility, but that the magnitude of the advantage is task-dependent.

He explained that research has shown that we do not see the same magnitude of differences using TV displays to test mono-stereo performance as we see when mono-bio performance is assessed under directly-viewed conditions. Dr. Pepper feels there are many reasons which might account for some of the differences, including unfaithful reproduction of:

- Absolute size and distance
- Absolute and relative depth cues
- Color and resolution
- Convergence and accommodation
- Motion parallax

Dr. Pepper has proposed research that would enable him to address aspects of these issues to determine the relative performance significance of these and other visual and perceptual factors for remotely-controlled manipulator tasks, and for vehicle navigation and guidance.

Dr. Frank A. Saunders – Sensory substitution tactile displays

Dr. Saunders explained his present work using tactile displays for the presentation of sound to deaf children, and discussed the problems which occur when the skin is stimulated electrically to achieve a tactile sensation. The system used with the deaf was demonstrated, and consists of 32 individual tactile stimulators worn around the waist on a belt. A bi-phase stimulating pulse results in zero direct current, thus avoiding electroplating the skin or any other effects which could be harmful.

He went on to mention that tactile stimulation is excellent for changing dynamic inputs because constant level stimulation habituates the tactile sensory channel. Data obtained from two-point threshold experiments has confirmed this because performance has been shown to be much higher when the points are presented sequentially.

Dr. Saunders has been working with ten deaf children in the Marin County schools, using the belt in conjunction with lip reading, and has been getting favorable results. The performance of his subjects has been equivalent to progress in learning a foreign language.

Dr. John Lyman – Prosthetics research

Dr. Lyman briefly discussed his many years' involvement in prosthetics research and gave insights on how the field has progressed through the years. Today, he is working with pattern recognition on the myoelectric signals from the surface of the shoulder to control an artificial arm. He went on to explain that they have not been very successful in providing feedback to the patient using electrocutaneous mapping. He discussed some of the problems related to electrocutaneous stimulation, including limited dynamic range and uneven current densities under the stimulating electrodes.

Dr. Lyman presented a preliminary report by one of his graduate students who has managed successfully to deliver 80 words of vocabulary through the skin at speech rates. These studies have been performed using three different, highly-motivated subjects. He then explained the research UCLA has done on electrocutaneous stimulation and discussed all the variables they have explored during their two-point threshold experiments.

The importance of artificial intelligence applied to automatic control also was discussed.

Dr. John Silva – Biomedical engineering and human factors

Dr. Silva discussed his extensive work in biomedical engineering and human factors. He explained the use of evoked cortical responses for measurement of visual and auditory system performance and recent developments in nonevasive measurement of blood pressure, echo cardiography and computer-aided cardiology.

The development of a remote communications system to provide expert advice to corpsmen on small ships, and a medical support stretcher for keeping the wounded stabilized during transport were presented. His work in the development of a head-rest control for a wheel chair and a stand-up wheel chair also were presented.

In assessing the state of the art in biomedical and human engineering, Dr. Silva stated that the most influential factors are the computer and the microprocessor. He said tremendous inroads are being made in the brain and neurophysiology areas and that bio-chemical technology also is on the verge of major advances. Electro-optic examinations are being made routinely inside the body, and he believes that computer-aided decision making and advanced decision theory will have a great impact on advanced remote systems.

Robert S. Gales – Audition

The characteristics of the human auditory system were described. Mr. Gales discussed those functions of the ear which should be incorporated into a remote listening system.

- Detection of emitting targets
- Classification/recognition/identification
- Localization

He explained that the ear does an excellent job in all the above functions because it is backed up with a large memory bank that enables it to detect, identify and localize instantly.

The way in which we localize sounds in space was covered in depth, with time difference of arrival, intensity and phase being the cues we use. He said recent research indicates that above 5000 Hz we localize in the vertical plane by analyzing the sound reflections off the pinna (the outer ear).

The presentation was concluded with a description of the phenomenon known as time separation of pitch, which is used by the blind to determine distance from large objects.

Dr. David L. Blank – Olfaction

The interest of the Naval Research Laboratory in understanding the neurophysiology of smell was discussed. Dr. Blank explained that what most of us think of as smell is really referred to as flavor and is comprised of smell, taste and other inputs from various nerve centers. Smell was explained to be less important in man than in most other animals, and that in man, smell or flavor is mainly an aesthetic sense.

Given the same odorant in different concentrations, man can identify only four or five different levels of concentration. With respect to absolute identification (naming different odors), man can differentiate only about 16 different odors at a time. Professional perfumers may differentiate 18 to 22 odors. It was explained that this sensory system is slightly better than other sensory systems in respect to identification.

Dr. Blank then explained the neurophysiology of the olfactory system. The similarities between the operation of a gas chromatograph and a functioning olfactory system were drawn, and the differential sensitivity of receptor cells to various odorants was discussed. He said that each individual receptor cell is sensitive to more than one chemical, so a different pattern of receptor firings is associated with each odorant (i.e., a cross-fiber pattern code).

He said an artificial nose, using a gas chromatograph, could be sensitive down to 10^{-15} molar, and that if a person defined what chemicals he was interested in looking for, a column could be designed especially for those chemicals.

Dr. C. Scott Johnson – Biosonar and animal electric field detection

Dr. Johnson presented a short motion picture of an experiment with a diver sonar which used transformed (into the human hearing range) porpoise echolocating signals. It was explained that humans performed as well as porpoises when tasked to identify a standard target when presented with a pair of targets.

Dr. Johnson emphasized the importance of allowing the diver full use of his head to scan the targets, and pointed out that an observer outside the pool did not do as well. He mentioned that the discrimination was a subjective one, and that the task came quite easily to the subject with very little learning involved.

Dr. Johnson went on to describe how some marine animals are very sensitive to electric fields. Sharks can detect an electric field of 10^{-8} volts per cm, or one volt in 1000 kilometers. This allows them to navigate using the earth's magnetic field. He stated that if we could simulate the shark's mechanism, we could detect the bearing to a submarine-size object at a distance of 10 kilometers. He observed that this is quite remarkable when one remembers that the background noise due to the currents causing electric field gradients in the oceans is 1000 times the sensitivity of the shark.

Dr. Carter C. Collins – Sensory substitution

Dr. Collins described accomplishments on the tactile representation of pictorial information. He has developed a device which uses converted TV camera images to drive a two-dimensional array of electrotactors situated on the user's abdomen. Pulse width variation presents the "light" intensity information. A blind man wearing such a 10 x 10 array learned a high-acuity-requirement electronic assembly task and kept up with sighted workers on an assembly line. He explained that after ten to twelve hours of practice with the device, one can learn to recognize a few dozen objects. Dr. Collins also has evaluated the device as a mobility aid, and has demonstrated the device by having the user avoid obstacles while navigating through a room.

Also, he described some of the problems of presenting the electrical stimulation and keeping the skin in contact with the electrotactors. For two-dimensional displays, mechanical stimulation was recommended for comfort. Jets of water also have been tried, and Dr. Collins said the skin does not do well in handling parallel information, but added that good use can be made of temporal scanning.

Dr. Collins described work done on his own in developing an artificial nose. The "nose" consists of three pairs of individually-coated thermistors that respond differently to the given odorants' latent heat of fusion. The three absorbent materials used were lanolin, albumin and polyvinyl chloride. Air carrying the odorant is pulled across the thermistor pairs and the normalized ratio of amplitude of responses from the three materials can be plotted and then classified.

Dr. John W. Hill – Manipulators

Dr. Hill explained the work he has done for S.R.I. and NASA which has incorporated tactile feedback and display systems into remote manipulators. He has implemented touch and proximity sensors and has used vibrotactors and air jets to provide touch sensations to the user.

He showed many methods of both contact and non-contact type sensors using passive and active means to achieve range and proximity information. He mentioned that all were laboratory systems, and to date no one has developed a decent practical tactile sensor.

Dr. Hill made a strong appeal for more work dedicated to developing hands. He feels that work done on end effectors is an area of concern that has not progressed in the last ten years, and that someone should be working on two fingers and an opposing thumb.

Dr. Hill now works in the artificial intelligence group at S.R.I., and says there is an inexhaustible number of excellent ideas that need to have money and good engineering put behind them. If the correct thrust can be made, impressive and sophisticated hardware can be developed without too much difficulty.

Dr. Larry J. Leifer – Manipulators

Dr. Leifer explained the wide array of disciplines he represents at Stanford University, including the A.I., E.E., M.E., and robotics groups. His background is in biomedical engineering, and because of this he is very interested in using manipulators to allow quadriplegics to do things for themselves.

He is oriented strongly toward human factors, and is very interested in the man-machine interface. He explained his heavy reliance on the use of distributed microprocessors in controlling the arm. In such applications he has incorporated extensive use of voice control.

He agreed quite emphatically with Dr. Hill that extensive work needs to be done to develop a "cybernetic" hand. He has built a parallel-jawed hand that was developed to pick up objects standing vertical or lying horizontally. In his present work he is trying to take the details of the task away from the user and be able to control the manipulator with task commands.

Dr. Thomas B. Sheridan – Teleoperators and supervisory control

Dr. Sheridan stated that, with the introduction of computers and artificial intelligence into the control of teleoperators, we are now in a better position to appreciate what man can do, and understand how people and computers can work together.

For a long time, Dr. Sheridan has been interested in mixing human and computer control. He explained his ideas on supervisory control of manipulators and undersea vehicles

He presented a short motion picture on work that has been done at MIT with a supervisory-controlled manipulator, and explained present studies investigating manipulation tasks using constrained visual systems. The present studies measure operator performance while varying the presented TV picture resolution, frame rate, and the number of grey levels.

The question was raised as to whether or not it is desirable to build a hi-fi sensing system or a sophisticated computer controlling system. He suggests it is not desirable to do either because they should be made to complement each other. He wants someone to build a high-fidelity sensor system that will make it easier for the operator to program the computer for supervisory control.

Dr. Sheridan agrees that a need exists for better sensing equipment, and that talk of the extensive use of artificial intelligence is like talking about fusion power. "It ain't gonna be here for a long time," he said.

Dr. Richard T. Swim

Dr. Swim was invited from the Naval Research Laboratory to explore that organization's potential inputs into the program.

He described the project in which a low-speed, laminar-flow, free-swimming submersible was developed. The vehicle is 4 feet in diameter, 20 feet long, and weighs 8,000 pounds. It has an internal volume of 125 cubic feet, 40 of which can be used to carry cargo or other experiments. The submersible runs on automobile batteries for 25 hours, enabling it to travel 125 miles. It runs under microprocessor programmed control and has sensors that maintain speed of advance and measure roll, pitch, and yaw. Water salinity and temperature also are measured and recorded.

OPEN FORUM DISCUSSION

FORM OF THE SUMMARY

The open forum discussion was an informal, unstructured dialogue which progressed freely from one topic to another. Therefore, it seemed better to summarize the viewpoints by subject matter rather than in chronological order. The open forum nature of the conference enabled many different points of view on teleoperator-related subjects to be expressed. This created an excellent, thought-provoking atmosphere. The discussions dealt primarily with the following subjects:

- System Characteristics
    - Anthropomorphism
    - Realism or Fidelity
    - Operator Involvement in Task Performance
- Mission/Task Characteristics
- Technology State-of-the-art
    - General Topics
    - Artificial Intelligence
    - Manipulators and Sensors
- System Development

SYSTEM CHARACTERISTICS

Anthropomorphism

The major questions addressed in this area were, "How much should the teleoperator physically resemble man?", and "How should it incorporate human performance characteristics?" Dr. Sheridan pointed out the pros and cons of these ideas.

He said we tend to make things in our own image when we do not understand them well. It is when we understand more about the functions that we realize we can perform the tasks better with systems that do not look quite so human.

In opposition to this, Dr. Sheridan said that if the teleoperator is structured like man, it is much easier for the operator to spatially identify with it, and this is necessary if stimulus incompatibilities are not desired. Stimulus incompatibilities must be kept to a minimum if the operator is to keep track of the position of the teleoperator "limbs." A system with proprioceptive feedback (feedback from sensors in the limbs) would be required.

Perhaps the consensus was expressed best by Dr. Leifer. He stated that what we want is to perceive the teleoperator's sensors as our own, and in all respects, the display and controlling hardware should be transparent to the operator.

Realism or Fidelity

Mr. Hightower feels strongly that a need exists for a real-time, high-fidelity system between the remote environment and the human operator. He pointed out that many of the conference participants are helping the handicapped who are deprived of some sensory or motor capabilities, and that the operator of the teleoperator will be chosen because he has full or exceptional capabilities.

Mr. Schneider pointed out that in many cases the hostile environments deprive the system of fidelity and, in some cases, all use of a particular sensory modality. For example, turbid water, smoke, fire or darkness severely deprive us of the use of the visual sense. The concept of sensory substitution as a method of solving these types of problems was discussed at length. Sensory extension, such as extended vision to the IR or UV wavelengths, or extending audition to the ultrasonic or infrasonic frequencies, were among the topics discussed.

The discussion pursued realism and its importance when dealing with the number of degrees of freedom needed for remote manipulation. Today's manipulators have far fewer degrees of freedom than the human hand, and provide little, if any, feedback to the operator. Generally, it was agreed that while it may not be necessary to provide all the degrees of freedom of the human hand and arm, more than the three to seven degrees currently available on today's manipulators would be useful, and that more realism should be incorporated into the implementation. The importance of providing the operator with tactile and kinesthetic feedback also was stressed.

Realism in terms of the visual sense was discussed. A system incorporating color, foveal-peripheral relationships, head- and eye-movement-following, variable convergence and accommodation were envisioned. It was stated that head-coupled TV's have been around for years and that a system had shown its utility as part of the Remote Unmanned Work System in Hawaii. It was in development and eventually removed from the system because of budget limitations.

Also mentioned was a head-coupled, helmet-mounted stereo system that would enhance realism by removing the inside-looking-out (through the window) effect associated with the most of today's viewing systems.

Dr. Blank and Dr. Saunders suggested that improved sensors could be built to take advantage of the principle of lateral inhibition in order to improve edge detection.

Operator Involvement in Task Performance

These discussions focused on the degree to which the operator should be involved in the details of a task. Dr. Leifer proposed considering the following metric:

Atomic Level (Simple motor tasks)	⟷	Complex Tasks

He suggested that man really wants to work at the level of directing tasks, not the atomic level of guiding each individual movement. Some of the other participants disagreed with that viewpoint, saying that man wants to be more involved and feel that he has things more under his control.

Mr. Katayama and Dr. Collins expressed the view that if all of the senses and motor capabilities can be provided, microprocessors and programming can be added to the system to do the more mundane portions of the job automatically.

MISSION/TASK CHARACTERISTICS

A great deal of the discussion was concerned with the need to define the missions and specific tasks which teleoperators would be used to perform. The main controversy was over the need for specificity in the definition of tasks. Dr. Leifer suggested the need for a goal, even if that goal were fanciful, so that accomplishments could be assessed.

Dr. Malecki said, and most participants agreed, that the desired goals and ultimate users must be identified. He said that at least the classes of tasks need to be defined. Mr. Hightower said that not only is a list of all task functions needed, but priorities must be assigned. Dr. Silva commented that a human-sensory-based technological platform was needed, but to build something useful, the tasks it will perform must be more specifically selected.

Dr. Silva also said that in examining the tasks, the environment in which the teleoperator is placed must be monitored to determine what information is relayed to the operator and how that information is displayed.

Lt. Col. Bowles stated that a big military problem today is target acquisition (e.g., Where is the target right now?). Mr. Armogida said that he had looked at some missions and tasks. Ordnance-disarming, diver-manipulating, and marine reconnaissance tasks also were discussed.

TECHNOLOGY STATE-OF-THE-ART

General

NOSC personnel raised the question as to whether or not technology can support the development of the concept of projecting the feeling of man's presence into the teleoperator's environment. They wanted to know where technology stands today, and solicited new ideas on approaches to solving this problem.

Dr. Lyman stated, and others supported, the need for a state-of-the-art survey.

From the sponsor's point of view, Lt. Col. Bowles said he wanted to know where the technological risks are in initiating this type of program, and what the opposition (mainly USSR) is doing in this area. Dr. Lyman responded to the latter question by saying the Soviets probably are well behind us at this time.

Several participants expressed the thought that today's technology can probably support the program but that the major problem is finding the money that would support integrating all those pieces.

Artificial Intelligence (AI)

Dr. Lyman was asked to comment on artificial intelligence. He replied that AI advances are being aided by:

- Cheap memory (good concepts require dense memory).
- Ability to manipulate data in condensed form (e.g., use of polynomial functions which describe a large amount of data).

Dr. Sheridan stated that parallel processing permits much more processing at a much faster rate, but cautioned that AI people tend to be unrealistic in terms of the time it takes to get the desired results.

Dr. Hill stated that years ago, artificial intelligence was oversold, but now results are being seen in the areas of speech and image recognition. He cautioned not to expect too much work that will be directly applicable to teleoperators.

Manipulators and Sensors

Dr. Lyman said that sensor development is proceeding at a rapid pace, particularly in the optics area, and said that you can buy eyes (miniature TV systems) but have problems with visual display. References were made to the development of eye-movement trackers and the existence of a tracker that does not require fixing the head.

The conferees agreed that the tactile skin sense presently is missing and that it is a very important area where little work is being done. Interest was expressed in a "second skin" being built by Union Carbide for prostheses.

Problems of disorientation due to the operator not being coupled to the motion of remote undersea vehicles were discussed. If the water suddenly becomes turbid and the vehicle moves, the operator has no idea where he is in relation to the vehicle's original position when the water calms. Mr. Hightower said the Soviet literature referred to similar problems which were reduced when the operator, in a dentist-like chair, was coupled into vehicle motion.

Dr. Lyman explained how much preprocessing of sensory data takes place before it gets to the brain, and the question was raised of how much preprocessing should be done at the remote site (i.e., before it is sent to the operator). He suggested that all direct sensory data could be given to the operator in the "raw" form because there is no sensory processor that approaches the capability of the brain.

While it was pointed out by Dr. Hill that manipulators can be made stronger, faster, and more accurate than the human hand and arm, the sensors are the items that are sorely lacking. Dr. Lyman agreed, and said that the sensory capabilities of man are an order of magnitude better than his manipulative capability.

Mr. Hightower felt the highest near-term priorities were:

- Building a hand that has the manipulative capabilities of humans (adaptable for many tasks).
- Recreating the visual aspects of the scene.

He restated his thoughts on the importance of the adaptability of man, and that the system should take advantage of what man has to offer.

Mr. Smith said that NOSC has obtained a visual tracking system from Honeywell which is used in an operational airborne missile guidance system. Mr. Katayama said that in a year or a year and a half NOSC would have a head (with eyes and ear) on an articulated boom, but he does not think the eye will have the foveal-peripheral relations of the human eye.

Dr. Johnson expressed the opinion that visual displays should not be substituted for the auditory channel in presenting the operator with acoustic information. Mr. Gales supported that viewpoint.

The problem of locomotion was touched on only briefly, and Mr. Smith said the program did not expect to build a teleoperator that walked like a man.

SYSTEM DEVELOPMENT

Three general items of importance were expressed:

- The need to investigate both the technologies and missions and to attempt to interrelate the two – (stressed by Mr. Spalding). Dr. Malecki thought this should be done in a quantitative, integrated way.
- The importance of investigating (1) the teleoperator as a system and defining the specific components, and (2) different types of operator displays and controls (a point made by Dr. Silva).
- The need to develop an approach that will pull advancing technologies together and integrate them into a teleoperator system (stated by Dr. Pepper and others). Dr. Pepper believes there will be no problem in marketing an integrated system once development has been initiated.

RECOMMENDATIONS

From the open forum discussions, the following items were extracted as recommendations for the Advanced Teleoperator Technology program. Some of these items already are in the preliminary program plan. It may be beyond the resources of the program to pursue all the recommendations, but other funding will be sought and other programs will be encouraged to insure that all important aspects of the technology are adequately treated.

- Analyze missions, develop task descriptions, and prepare scenarios of potential teleoperator development.
- Conduct a state-of-the-art survey of the technologies applicable to teleoperator development.
- Compare mission needs with the state of the art and identify gaps and risks.
- Set goals. Decide what kind of teleoperator (if any) is to be built and what its characteristics and capabilities will be.
- Impart to the operator the feeling that he is the teleoperator at the remote location. Strive for high fidelity in simulating the human senses at the teleoperator and present the information to the operator in real time.
- Improve sensors with respect to incorporating more of the characteristics which add realism (e.g., eye movement, foveal-peripheral relations, variable convergence, etc.).
- Develop new sensors for olfaction, proprioception and touch.
- Develop a manipulator with more degrees of freedom (greater than 6) and attempt to create realistic control by modeling the end effector like the human hand. Incorporate the senses of touch and proprioception in that manipulator.
- Integrate the products of relating technologies (sensors, manipulators, artificial intelligence, etc.).

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